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Development and Analysis of Millennial-Scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)
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The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
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Keck Geology Consortium: Projects 2007-2008
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ASSESSING THE PACIFIC NORTH AMERICAN TELECONNECTION: LAURENTIAN GREAT LAKES WATER LEVELS AND GULF OF ALASKA TREE GROWTH

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INTRODUCTION

Variations in Great Lakes water levels have implications for commercial navigation, water supplies, recreation and tourist industries, fishing, and lake ecosystems (Mitchell, 2002). Modeling efforts are underway to predict future lake levels under various climate change scenarios (Lofgren et al., 2002; Lofgren, 2004; Kutzbach et al., 2005). There are several factors, regionally and continentally, that affect lake levels, including precipitation, evaporation, ice cover, runoff, and wind.

Tree-ring chronologies from the Gulf of Alaska (GOA) have recently been found to correlate well with Laurentian Great Lakes water-level data (Krawiec, et al., in review). This correlation is likely due to the Pacific North American teleconnection pattern (PNA) that links North Pacific climate with evaporation and precipitation rates in the Midwest of North America (Sheriden, 2003, Krawiec, et al., in review). One of the aims of this study is to further test and assess the PNA as it relates to the Great Lakes region. Secondly, this study is aimed at reconstructing past lake levels for Lake Michigan (44˚00' N, 87˚00' W) and Lake Huron (44˚50' N, 82˚25' W) in the range of 200-300 years beyond historical records by utilizing tree-ring chronologies from the GOA.

There are two of reasons for using tree-ring data from the GOA rather than the Midwest. GOA trees are records of North Pacific temperature, but they are more strongly correlated with Midwestern climate patterns than trees from around the Great Lakes. The second reason is GOA trees extend further back in time than Midwestern trees, therefore allowing reconstructions to go further back.

Teleconnections are described by Bridgman and Oliver (2006) as linkages between climate anomalies at some distance from one another. They play an integral role in ocean-atmosphere interactions and global climate processes. The Pacific North American Teleconnection (PNA) is an alternating pattern of temperature and precipitation conditions between the central Pacific Ocean/southeastern United States (these two areas act together), and western Canada (Bridgman and Oliver, 2006). Like most teleconnections, it has a positive and negative phase.

During PNA positive winters, low pressure systems in the North Pacific and an amplified ridge across the interior of North America tend to cause above-average precipitation totals and temperatures in the Gulf of Alaska and extending into the Pacific Northwestern U.S., and below-average totals over the upper Midwestern U.S. (NOAA, 2005).

During PNA negative winters, high-pressure systems occur over the Northern Pacific and low pressure occurs over the Midwestern United States, with increased precipitation in the Midwest and Ohio River Valley (Rogers and Coleman, 2003). The climate anomalies of the PNA tend to be more pronounced in the winter months (Bridgman and Oliver, 2006). It is also strongly influenced by El Niño Southern Oscillation (ENSO) (NOAA, 2005). The positive phase of the PNA pattern tends to be associated with Pacific warm episodes (El Niño), and the negative phase tends to be associated with Pacific cold episodes (La Niña).

Study Area

This study employs chronologies from eight sites from around the GOA (Fig. 1). Overall, the GOA from the Inside Passage in the southeast to the Aleutian Islands in the west maintains a wet climate with average January and July temperatures of 13.3˚C and -2.2˚C, respectively, for the Inside Passage, and -6.1˚C and 13˚C, respectively, for the South Coast area (Alaska Climate Research Center, 2008).

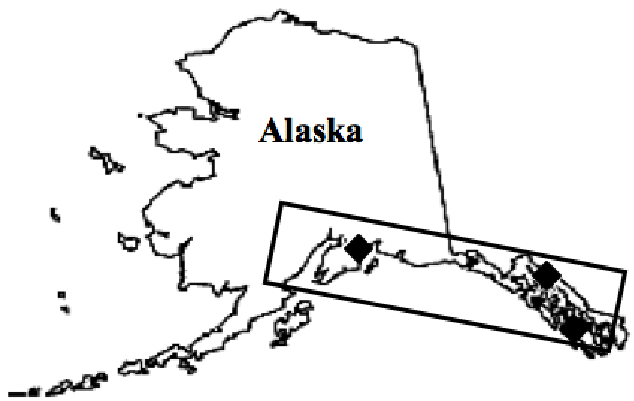

Figure 1: Study areas in the Gulf of Alaska denoted by points in the rectangle. A majority of samples were taken from the Kenai Peninsula, centered on the point.

Old growth forests in the GOA have provided optimum sampling sites for climate studies due to their longevity and sensitivity to climate. Some living species of trees have been found to date back to nearly 1100 A.D. (Wiles, et al., unpublished data). Records of temperature and precipitation have been reconstructed from such trees for centuries beyond the written record (Wiles, et al. 1998). Climatic patterns such as the Pacific Decadal Oscillation (PDO) have also been reconstructed using ring-width chronologies (D'Arrigo, et al. 2001, Wilson et al. 2006). For this study the species that were sampled included mountain hemlock (Tsuga mertensiana), Sitka spruce (Picea sitchensis), and subalpine fir (Abies lasiocarpa). These species, especially the hemlock, respond to even slight changes in climate (temperature and precipitation), as evidenced in the ring-width record. The cores, taken by a team of people, come from elevations between 8 and 1740m (International Tree-Ring Database, 2008).

The Great Lakes lie at the confluence of cold, dry Artic air masses and warm, humid air from the Gulf of Mexico. This results in an overall mild climate with potentials for brief frigid and hot periods. The climate immediately surrounding the Great Lakes differs greatly from the climate more distal from the lakes. The lake effect contributes to significant increases in precipitation over the land bordering the Great Lakes (Great Lakes Information Network, 2006).

Figure 2: A core extraction of a mountain hemlock (Tsuga mertensiana).

METHODS

Tree cores were taken with standard 5mm increment borers (Fig. 2). Typically two cores were taken from each tree (20-40 trees per site), but in some instances heart rot allowed only one core to be taken. The cores were air dried and then glued in wooden mounting grooves and sanded to a fine finish with up to 600 grit sandpaper to expose fresh ring surfaces. The number of rings in each core was counted and measured to the nearest 0.01mm. Ring-widths were then measured using a micro-caliper, which was attached to an electronic counter that fed the information into a software program, called Cofecha, to crossdate the chronologies (Grissino-Mayer, 2001).

The dendrochronology software program PCReg was used in this study. PCReg employs principal component regression analysis to come up with time series correlations of tree-ring and climate data (Cook and Kairiukstis, 1990). The program was run by inputting tree-rings width data as the predictor and averaged annual lake data calculated by the Great Lakes Environmental Research Laboratory (GLERL, 2008) as the predictand. Lake level reconstructions were then output for the past few centuries.

Calibration and verification testing (Cook and Kairiukstis, 1990) was performed by splitting the 87 year common period of climate data and tree-rings into two 43 year intervals. The earlier interval of 1901-1943 was used to reconstruct a model that was verified over 1944-1987, and then the exercise was reversed. The early, 43-year calibration model explained 32% of the variance, and the latter model explained 45% of the variance. This evaluation is typically used to evaluate dendroclimatic reconstructions to demonstrate the validity of the model for predicting lake levels based on the North Pacific tree rings. The full 87-year period was then used to develop the final lake level reconstruction.

RESULTS

A collection of eight temperature-sensitive ring-width series from the Gulf of Alaska (GOA) was compared with monthly Lake Michigan and Huron water-level data (Table 1). Each of the eight tree-ring series was negatively correlated (significant at the 0.05 confidence level) with averaged annual December-June Lake Michigan levels. R values for the individual correlations ranged from -0.34 to -0.48. The percent explained variance for the composite record using all of the eight series was 35.8%. The common first year among the eight series is 1785 and the common last year is 1987, as

Name	Full Period	Species	Correlation-Six Series (Huron)	Corr.-Eight Series (Huron)	Corr.- Six Series (Michigan)	Corr.- Eight Series (Michigan)
Exit Glacier	1574-1988	Sitka Spruce	-.51	-.51	-.49	-.48
Water Supply	1727-1989	Mountain Hemlock	N/A	-.34	N/A	-.34
Ellsworth Glacier	1543-1991	Mountain Hemlock	-.40	-.41	-.42	-.42
Rock Glacier	1514-1992	Mountain Hemlock	-.41	-.42	-.42	-.43
Wolverine Glacier	1247-1991	Mountain Hemlock	-.45	-.45	-.47	-.46
Wrangell Pinnacle	1343-1999	Mountain Hemlock	-.43	-.43	-.40	-.40
Taku Glacier	1785-1987	Sitka Spruce	N/A	-.51	N/A	-.45
Lake Minotaur	1584-1992	Subalpine Fir	-.41	-.40	-.38	-.38

Table 1: The eight chronologies used in this study.

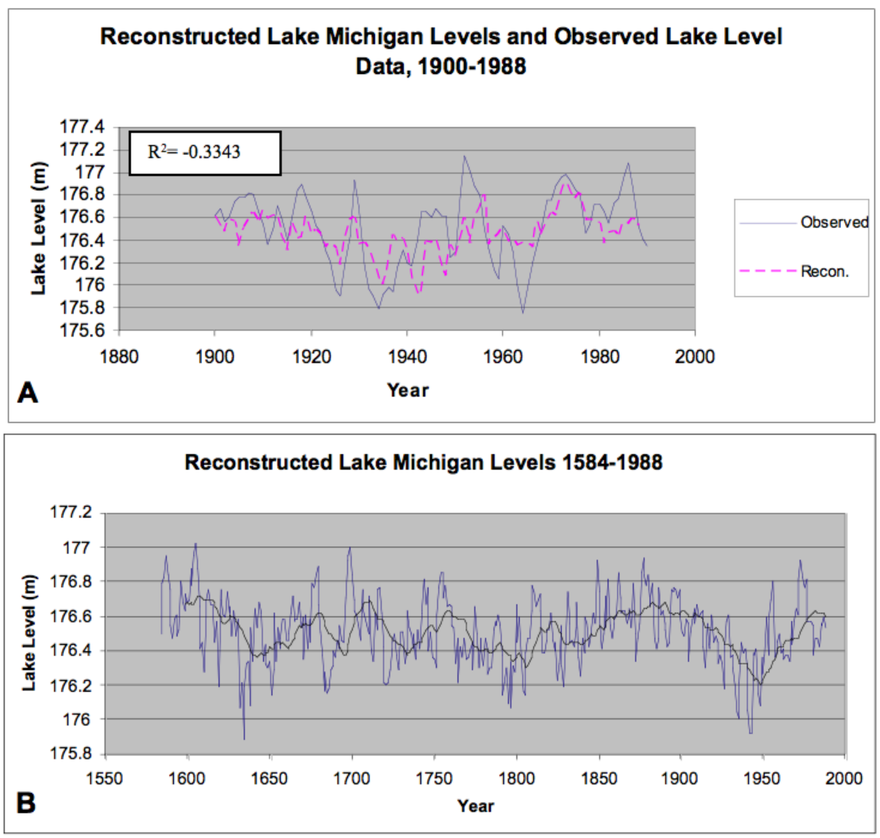

Figure 3: (a) Reconstructed lake levels are compared with recorded lake level data for the same period. The reconstruction using the six chronology model explains 33.4% of the variance (seen here), and the eight chronology model explains 35.8%. (b) The Lake Michigan reconstructions back to 1584 are shown using the six chronology model.

limited by the dates of the ring-width series. These same eight chronologies, when compared with Lake Huron lake levels for the months December-June, yielded r values between -0.34 and -0.51. The percent variance explained was 39.7%, also significant at the 0.05 confidence level.

Upon removing two of the series from the comparison, Taku Glacier (beginning year 1785) and Water Supply (beginning year 1725), the common first year is then 1584 and the common last year is 1988. This enabled the reconstructions to go further back in time than the eight series model. These six series correlated between r = -0.38 and -0.49 for Lake Michigan, again at the 0.05 level (Table 1). The percent variance explained is 33.4% (Fig. 3a). For Lake Huron, the correlations were between r= -0.41 and -0.51, and the percent variance was 35.6% (Fig. 4a).

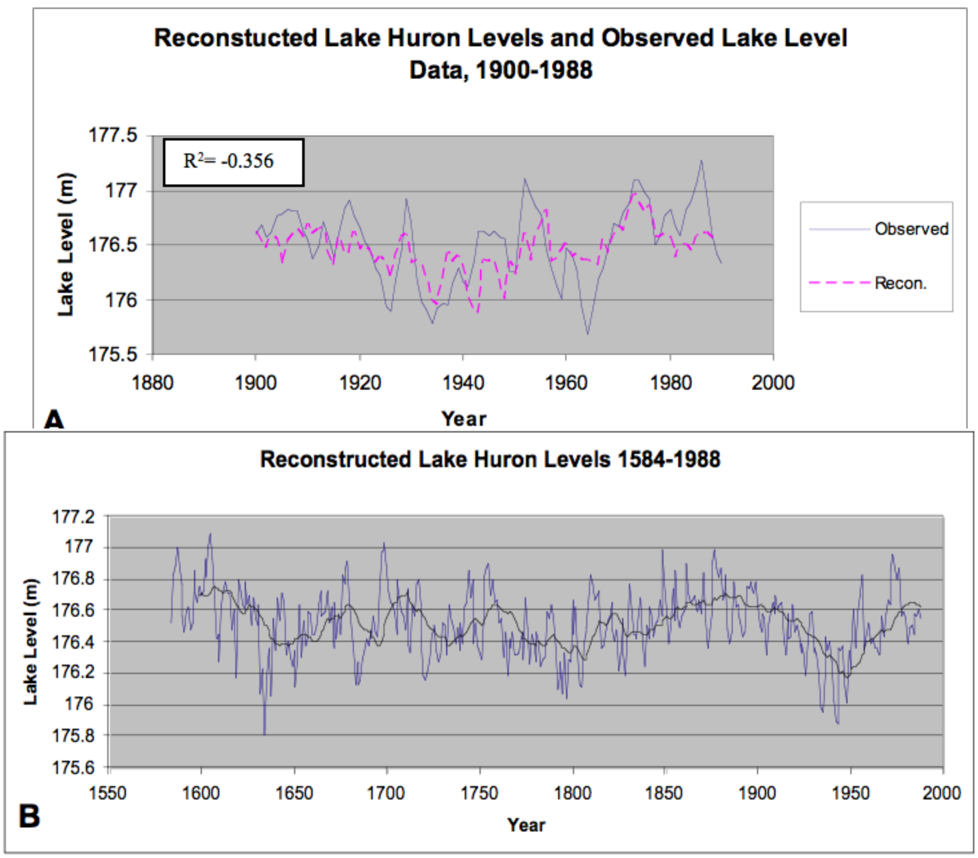

Figure 4: (a) Reconstructed lake levels are compared with recorded lake level data for the same period. The reconstruction using the six chronology model explains 35.6% of the variance (seen here), and the eight chronology model explains 39.7%. (b) The Lake Huron reconstructions back to 1584 are shown using the six chronology model.

DISCUSSION

Tree growth in the GOA primarily reflects growing season temperatures (Wiles et al., 1998; D'Arrigo et al., 2001). The Lake Huron and Lake Michigan reconstructions rely on the relationship between tree growth in the Gulf of Alaska and GOA ocean-atmosphere temperatures, which in turn, are strongly and negatively correlated with Lake Huron and Lake Michigan levels. When temperatures in the North Pacific are low (high), Lakes Huron and Michigan levels are high (low). Additionally, when precipitation in the North Pacific is high (low), lake levels are low (high). As stated in the introduction, during the PNA's positive phase the Pacific Northwest experiences above-normal temperatures and precipitation and the Midwest tends to experience colder temperatures and lower precipitation. Fluxes in precipitation greatly affect the levels of the Great Lakes.

Lake Michigan and Lake Huron levels were reconstructed back to 1785 using an eight-chronology model and to 1584 using a six chronology model. Lake Michigan exhibited notable high stands in the late 1500s, very early 1700s, and for most of the second half of the 1800s. Notable low stands occurred during the mid-1600s, late 1700s, and mid-1900s (Fig 3b). Lake Huron exhibited high and low stands around the same time periods (Fig. 4b). This is likely due to the fact that, because the two lakes are connected by the Straits of Mackinac, they are hydrologically considered one lake (Brinkmann, 1986). The Great Lakes as a whole are an interconnected body of water—what happens in one lake is felt by the other lakes downstream of it. If one lake is experiencing above normal precipitation and lake levels, the lakes to the east of it will also experience higher lake levels to some degree (Croley et al., 1998). The reconstructed lake-levels appear to oscillate on a multi-decadal and century scale. The multi-decadal periodicity is likely due to PDO cyclic behavior, while the higher frequency 5-9 year range is likely associated with ENSO activity. ENSO is another significant source of variability that influences the climate of the Great Lakes, and is also closely related to PDO and the PNA. This study further demonstrates the relationship between PNA, ENSO, and PDO due to the correlations observed between North Pacific tree growth and Great Lakes water levels. The century-scale oscillations seen in the reconstructions, from about 1640-1800 and 1800-1950 (Figs. 3b, 4b) suggest that longer-term controls may also be acting on the Great Lakes.

ADDENDUM

It has very recently come to the author's attention that one of the chronologies employed in this study is not from the specified study area (GOA). This issue will be fixed in subsequent publications; however, the removal of this chronology has a negligible effect on results.

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